

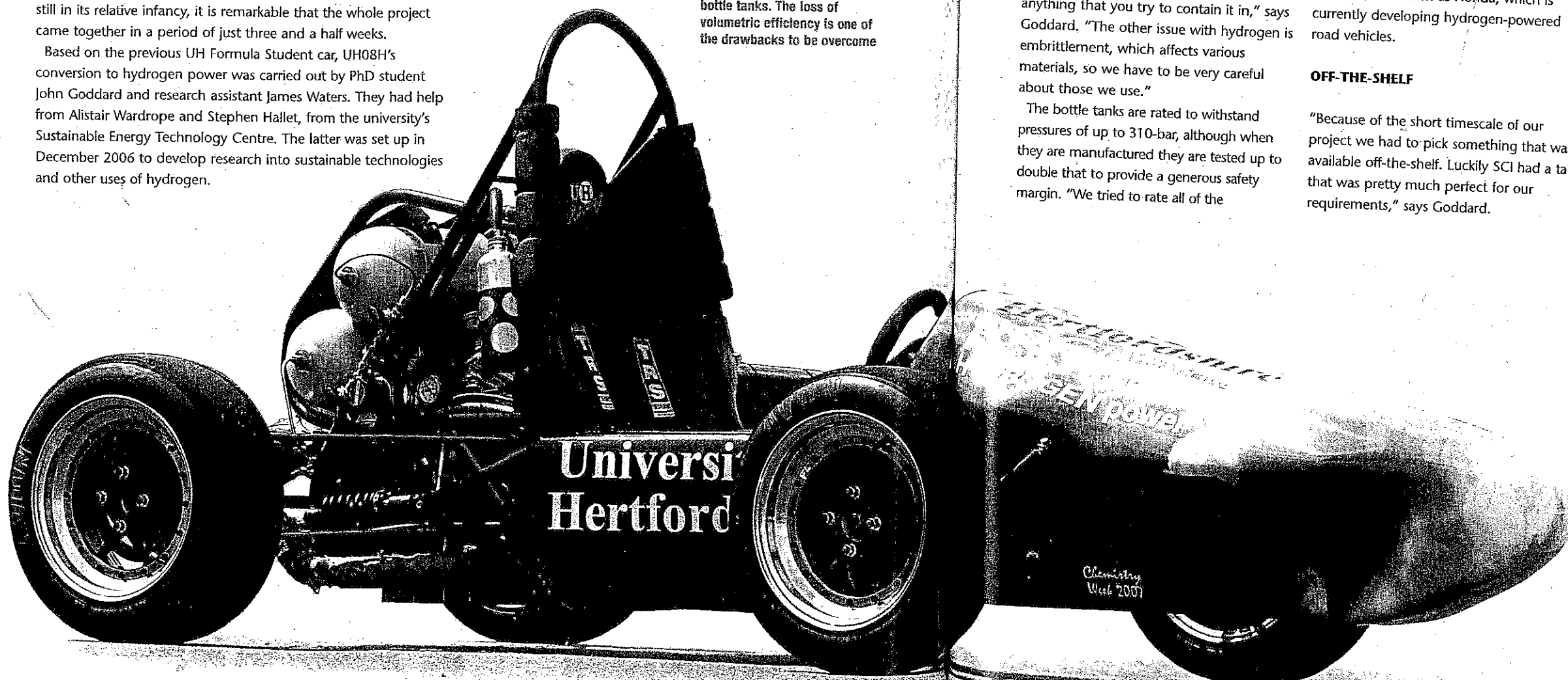
HYDROGEN HEROICS

The University of Hertfordshire offered a fascinating glimpse into the future when it entered a hydrogen-fuelled car in the Low Carbon Demonstration event held during the 2007 Formula Student competition. By Alan Lis

NOT ONLY was UH08H the first hydrogen-fuelled vehicle to be seen at Formula Student, it was one of few such cars built to date. Given that the development of hydrogen as an automotive fuel is still in its relative infancy, it is remarkable that the whole project came together in a period of just three and a half weeks.

Based on the previous UH Formula Student car, UH08H's conversion to hydrogen power was carried out by PhD student John Goddard and research assistant James Waters. They had help from Alistair Wardrope and Stephen Hallet, from the university's Sustainable Energy Technology Centre. The latter was set up in December 2006 to develop research into sustainable technologies and other uses of hydrogen.

BELOW The hydrogen is stored in compressed gas form, in a pair of nine-litre filament-wound bottle tanks. The loss of volumetric efficiency is one of the drawbacks to be overcome



UH08H's hydrogen is manufactured using farm waste. This is put into an anaerobic digester from which methane is obtained. This is burnt to generate the electricity used to power an electrolyser that produces the hydrogen. Alternatives for generating green hydrogen are to use an electrolyser powered by a solar panel or a wind turbine to power the electrolyser.

On the car the hydrogen is stored in

components of the fuel system as highly as the tanks," he says. "Because hydrogen fuel is new technology for automotive applications, it's quite hard to get parts in the UK; we had to go to the USA and Canada in many cases. The logistics of getting the project together has been one of the main challenges."

The hydrogen is essentially used in the same way as gasoline fuel, albeit with obvious differences in the way that the fuel

"We wanted to have two tanks on the car because it was better for packaging than one large one. The tanks are quite hard to get hold of, because they tend to be made in small batch quantities for specific applications, and they are also expensive."

Storing the hydrogen as compressed gas was seen as the obvious choice for the project as it offered a simpler approach than cryogenic tanks, where the hydrogen is stored at very low

temperatures. In the latter, the hydrogen is collected in a type of membrane, like a fuel stack system, but it is a very heavy

system. Gaseous hydrogen does not need a fuel pump, as it can be controlled by line pressure using a simple gas bottle regulator.

So how does hydrogen compare as fuel to gasoline or alcohol?

"Hydrogen is a pure fuel but the problem is that as a gas it is not very dense and therefore takes up a lot of space," says Goddard. "To get a lot of fuel into the engine is quite difficult. What you usually find is that the air in the cylinder is displaced by some of the hydrogen and as a result you tend to lose 30-40% of the volumetric efficiency. That loss can be recovered by using a supercharger or by increasing the displacement of the engine."

"The injectors we use are run at 5-bar and they are a low impedance injector but they are quite over-rated for our application. They are usually found on a bigger generator type of engine so they are somewhat oversized."

"Slow running gives us an issue with the injectors either being on and open too much or off and not delivering enough hydrogen. That could be solved by using another type of injector or by doing something clever with the sequencing of the injectors so that they only fire every other cycle or something like that. We haven't actually tried that yet but we might find that we are losing too much hydrogen and it's not as efficient."

"The fuel can be run from a rich mixture down to a very lean mixture, and in that respect it's almost like a diesel engine – all that leaning the mixture does is reduce power, it doesn't affect how smoothly the engine works. However, it does have some effect on emissions because the richer you run with hydrogen, the more likely you are to generate higher combustion temperatures that will produce nitrous

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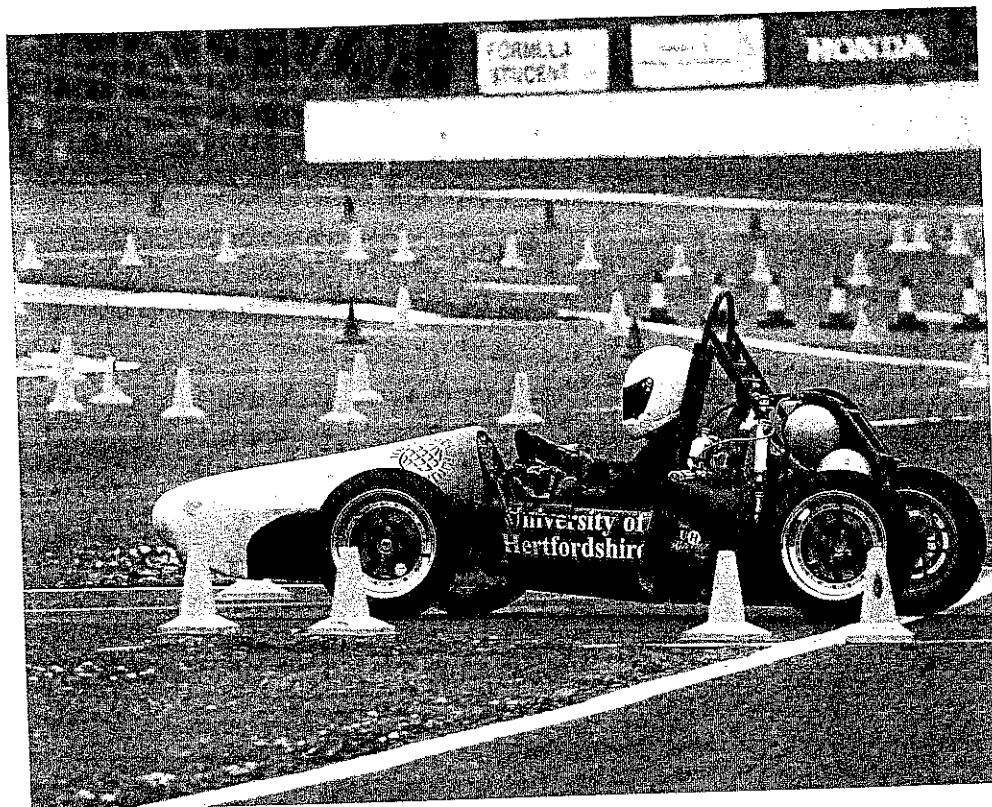
compressed gas form and contained in two nine-litre bottle tanks. They have solid aluminium walls that are also filament wound with glass fibre and carbon fibre, giving them high strength and minimum leakage. "That's important because the hydrogen molecule is the smallest known molecule and tends to permeate through anything that you try to contain it in," says Goddard. "The other issue with hydrogen is embrittlement, which affects various materials, so we have to be very careful about those we use."

The bottle tanks are rated to withstand pressures of up to 310-bar, although when they are manufactured they are tested up to double that to provide a generous safety margin. "We tried to rate all of the

is transported in the fuel lines to the special injectors in the cylinder head. The fuel lines and most of the fuel system have to be made in stainless steel and are produced by certified manufacturers, in this case by Structural Composite Industries in Pomona, California. The company also supplies car manufacturers such as Honda, which is currently developing hydrogen-powered road vehicles.

OFF-THE-SHELF

"Because of the short timescale of our project we had to pick something that was available off-the-shelf. Luckily SCI had a tank that was pretty much perfect for our requirements," says Goddard.



LEFT The first hydrogen-powered car in the history of Formula Student embarks on a lap

OPPOSITE Although the UH08H project was put together in a particularly short timeframe, it offers an intriguing insight into a possible long-term solution in the search for alternative fuels

oxide – which is a greenhouse gas. Otherwise you would usually just produce water vapour as exhaust emission.”

Formula Student cars are normally required to run with a 20 mm air inlet restrictor. Even with optimised inlet and exhaust valves, that tends to result in a loss of about 30% volumetric efficiency at the

Explosions are not unknown in the inlet manifolds of gasoline cars and are much more likely with hydrogen.”

Fuel ignition is run at 0 degrees advance because of hydrogen’s tendency to pre-ignite and its very quick burning characteristics. “The compression ratio on the engine we ran was in line with the

a fuel in Formula Student is environmental because there is no carbon dioxide, carbon monoxide or hydrocarbons in the exhaust emissions. “We are trying to show that motorsport can be green,” he says. “The other plus is that it runs like a gasoline engine so the sound is like a conventional engine as opposed to an electric vehicle,

which doesn’t make any sound that you would associate with a normal car.

“At low RPM, where it is likely to pink, a hydrogen-burning engine sounds a little ‘diesely’ but once ours is running above 4000 RPM it

sounds to all intents and purposes the same as a petrol engine. When it’s passing by, you wouldn’t really know if it was running on one fuel or another.

PROBLEM WITH STORING HYDROGEN

“As far as disadvantages go, storing hydrogen is the biggest problem. The fuel is used quite quickly and in our system we can only store about half a kilogramme of hydrogen. We wanted to be able to carry enough fuel to run for 22 kilometres – that would be the equivalent of about 4.5 litres of gasoline – but our initial tests have shown that we won’t achieve that figure.

We would need another tank on the car to store enough hydrogen, or we can increase the pressure under which the fuel is stored in the existing tanks. But of course that means higher spec components and more cost.”

Another disadvantage of hydrogen fuel is increased wear and tear on the engine. The pre-ignition issue means that components can suffer badly at low RPM, especially the pistons. “You also have to avoid materials like titanium in the valves and other components because of the embrittlement caused by the hydrogen,” says Goddard.

“In operation we had trouble with starting the engine because it is designed to be quite high revving and there is a large amount of cam overlap. On cranking, the engine was not turning fast enough to prevent the hydrogen escaping past the inlet and exhaust valves before the engine speed got high enough. A VTEC, or some kind of valve control system, would help solve that problem but because we didn’t have anything like that on our engine it became a bit of an issue for us.”

The hydrogen project was backed by a grant from the Royal Society of Chemistry, but Goddard and Waters got access to the funds only three and a half weeks prior to the Formula Student event. “That was all the time we had to get the tanks shipped over from America and to get together all the other parts,” says Goddard. “At the same time we had to alter the car to provide a safety cage, devise a secure way of holding the tanks and arrange all the other fixtures.

CAM PHASE SENSORS

“We also had to replace the entire electronic fuel control system with a much more advanced one that would work with hydrogen fuel. That meant adding things like cam phase sensors. When all of that was done, the engine had to be assembled, the systems pressure tested and then we had to get the engine to start. After that we were into calibration testing on the rolling road. It was an amazingly short time frame which involved a lot of late nights and early mornings.”

The day before the Low Carbon Demonstration Event, which was held over the final two days of Formula Student, the engine was run in the car on the UoH rolling road and basic calibration was done.

Later that Friday morning, UH08H turned its wheels for the first time under hydrogen power on an access road at the university campus before it was trailed to Silverstone that evening.

“We had the chief scrutineers look over it because we wanted their opinion and to know if we would be allowed to run it the next day,” says Goddard. “Luckily they said they were happy with what they saw and told us to bring it back the next day for the normal scrutineering and safety checks.

“We got the car through the inspections and tests during Saturday and I managed to do a single lap of the sprint course at the end of the day. By then we only had about 20-bar left in the tanks, which was just about enough for one lap. The time was 4.5 seconds from the fastest cars but I had very little power because there was almost no hydrogen in the tanks. You have to lean off the mixture as the gas runs out and you lose power.

ROLLING ROAD RUN

“On the Saturday evening we took the car back to the university, put it on the rolling road and changed a few things to try and improve the performance using what we had learned during the day. When we went back to Silverstone the next morning, I started off a run with full tanks and got halfway around the first lap when I felt the engine starting to seize and the crankcase broke. That was only the third time that the car had been driven. It had been on the

rolling road for only a few hours before it went to Silverstone so it was still a very raw product, the work of two guys in three and a half weeks, to show what could be done.”

At the time of writing, the long-term future of this fascinating project was unclear although the UH08H car will be on display at the RSC’s Chemistry Week exhibitions up and down the UK during November 2007

Goddard and Waters are keen to see the project developed to its full potential. “We want to do a thorough investigation of what happened to the engine that we broke. We had to start the engine from cold because we had found that it was incredibly difficult to ‘hot start’. That meant quickly running it up to full load, which probably added to our problems.

“This is a part-time project for us, so obviously we can’t give it the full-time commitment it needs. We would love someone to get involved in the project as an industrial partner and take it to the next level by looking at things like supercharging, direct injection, better packaging and the optimisation of things like ignition timing, cam timing and so forth.

“If someone wants to get involved and help us out, we’ve got good facilities to do it. We just need a person sponsored to carry out the work. That would be fantastic. It’s one of the first cars of its kind in the world. It would be great to take the initial project and develop it into something that is robust and reliable and a good demonstrator of a new technology.”

Any takers? **LI**



“If the ignition’s advanced by more than five degrees, you can find that the engine will start to fire backwards”

top end of the power range in a gasoline engine. After talking to the Formula Student organisation, Goddard and Waters removed the restrictor from the hydrogen engine.

“By doing that we were not going to be making loads of extra power but there was the advantage that we then didn’t have a plenum in which air and hydrogen was collected,” Goddard explains. “When the engine starts, although the fuel injection system is full sequential, how the injectors and engine fires is quite random. Because hydrogen escapes very quickly, there is a risk that we could get hydrogen coming back into the inlet manifold and that was something we wanted to try and avoid.

gasoline engine because we didn’t have time to change it – ideally you would want to increase it,” he says. “It does still need a spark plug to give it the initial energy. The plugs we used are conventional but with a higher than normal heat range, although lower temperature ones would also work if need be.

“Advancing the ignition doesn’t really give you an advantage because the hydrogen fuel burns so quickly. In fact, if you try to advance the ignition it will start to pre-ignite on a warm engine. If it’s advanced by more than five degrees, you can find that the engine will start to fire backwards.”

The main advantage of using hydrogen as